ABNORMAL RHYTHMS OF SPEECH IN PATIENTS WITH IDIOPATHIC PARKINSON'S DISEASE

A. Bandini [1,2], F. Giovannelli[3], M. Cincotta[3], P. Vanni[3], R. Chiaramonti[3], A. Borgheresi[3], G. Zaccara[3], C.Manfredi[1]

[1] Department of Information Engineering, Università degli Studi di Firenze, Firenze, Italy
andrea.bandini@unifi.it, claudia.manfredi@unifi.it
[2] Department of Electrical, Electronic and Information Engineering (DEI) "Guglielmo Marconi", Università di Bologna, Bologna, Italy
[3] Unit of Neurology, Florence Health Autority, Ospedale "Nuovo San Giovanni di Dio", Firenze, Italy

Abstract: **Parkinson's disease (PD) involves impairments of voice an speech (hypokinetic dysarthria). Dysprosody is one of the most common features of PD speech, that includes alterations of rhythm and velocity of articulation. The aim of this study is the evaluation of rhythm alterations of speech in Parkinsonian patients during a sentence repetition task. 13 PD patients (9 male and 4 female) and 9 healthy controls (4 male and 5 female) were tested. Results show significant differences between the two groups as far as parameters T_{inter} (time interval between two consecutive sentences) and D (percent of speech time with respect to sentence duration) are concerned. In particular, T_{inter} is larger in PD patients while D is higher in the control group. These preliminary results show that PD patients may exhibit longer pauses between adjacent sentences and a lower percentage of "speech time" during a whole repetition period. Thus, the decrease of D leads to an increase of NSR (Net Speech Rate, defined as the number of syllables per second). This study confirms that speech in PD patients is characterized by short rushes followed by inappropriate pauses.**

Keywords : **Parkinson's disease, dysprosody, hypokinetic dysarthria, speech rhythm, speech motor performance**

I. INTRODUCTION

Idiopathic Parkinson's disease (PD) is a neurodegenerative illness that involves neurons in the zona compacta of the substantia nigra of the midbrain and other pigmented nuclei [1-3]. This pathology is associated with a great variety of motor (tremor, stiffness, bradykinesia, postural instability) and non-motor symptoms (depression, cognitive impairments, sleep and mood disorders), that significantly reduce the quality of life of patients. [4,5]. The main signs of the disease include impairments of voice and speech (hypokinetic dysarthria), which affect about 70% of PD patients [6].

These subjects might present alterations related to all speech dimensions (i.e. respiration, phonation, articulation and prosody). Therefore, PD patients might present reduced variability of pitch and loudness, hoarseness, reduced stress, imprecise consonant articulation, inappropriate speech silence and speech rate alterations [7]. Such variations may debut in the early stage of the disease [8].

These reasons, together with the non-invasivity of the acoustic measurements of voice, have brought researchers to identify features of voice and speech that could discriminate PD patients from healthy controls, as an aid to early diagnosis and tracking of the disease progression. One of the most common speech impairments in Parkinson's disease is dysprosody, that includes alterations of rhythm and velocity of speech, velocity of articulation and speech/pause ratio [7]. Many authors conducted studies on prosodic patterns of voice in PD patients, assessing parameters related to speech rate. Skodda et al. [9] found a speech rate variation (defined as the number of syllables per second) that follows the evolution of the disease. This modification is characterized by an articulatory acceleration in the early stages of the disease, followed by a slowing in advanced stages. Speech rate measures were also used to test the dopaminergic therapy effects on Parkinsonian voice. However, no significant differences were found during this pharmacological treatment [10]. A widespread task, used to evaluate speech rhythm disorders, is the syllable repetition task (oral diadochokinetic test). It was shown that PD patients tend to have less control on rhythm stability during this task, with a tendency to increase the pace of repetition. These results reflect a dysfunction at the level of basal ganglia that control the temporal regulation of a motor sequence [11]. Rhythm alterations derived from the oral diadochokinetic test were found also by Rusz et al. [12], where PD patients presented a fewer syllables per second with respect to healthy control subjects. Moreover, the evaluation of prosody from the reading of a text or a free monologue showed differences in the mean number of pauses between PD patients and controls.

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The aim of this study is to identify the presence of rhythmic alterations in the parameters related to speech rate in PD patients during a sentence repetition task.

II. METHODS

Subjects: 13 patients with idiopathic Parkinson's disease were recruited at the Department of Neurology of the Hospital "San Giovanni di Dio" of Firenze, Italy. Patients' age ranged from 53 to 83 years (mean: 72 years; standard deviation: 9.7 years), 9 patients were male, while the other 4 were female. At the moment of the experiment, disease duration ranged from 3 to 12 years (mean: 7.2 years, SD: 2.9 years). All PD patients were under levodopa medication and were tested during their "on" state.

A group of 9 healthy subjects was tested as control group (age: 34-73 years, mean: 59.6 years, standard deviation: 12.8 years), 4 male and 5 female.

All subjects were Italian native speakers. Signed informed consent was obtained from all the participants.

Experimental settings: Each subject was asked to repeat a standardized Italian vocalic sentence ("*Il bambino ama le aiuole della mamma*") at least 10 times, as spontaneously as possible, at comfortable loudness.

Speech signals were recorded on a standard personal computer using Audacity software (version: 2.0.3) with a Shure SM58 microphone and a Tascam US-144 board. The samples were digitized at a frequency of 44.1 kHz. The microphone, fixed on a boom, was positioned at a distance of 5 cm from the subject's mouth. The experiments were conducted in a quiet room of the "San Giovanni di Dio" hospital, and subjects were required to remain seated during the test.

Analysis: The acoustic analysis of the acquired signals was carried out at the Biomedical Engineering Laboratory, Department of Information Engineering, Università degli Studi di Firenze, Firenze, Italy.

As a first step an automatic voiced-unvoiced segmentation was performed in order to identify and "isolate" sentences in the whole signal. The algorithm implemented [13] splits the whole signal in short frames of the same length whose energy is evaluated and stored in an "energy vector". The Otsu's method applied to the energy histogram allows finding two thresholds that allow the separation between two classes (voiced and unvoiced frames). An example is reported in Fig. 1 where the test sentence is successfully segmented into two voiced parts.

Afterwards the following parameters were extracted:

– $T_{sentence}$: sentence duration (in seconds), calculated as the time interval between the beginning of a sentence and that of the next one;
– T_{inter}: inter-sentence duration (in seconds), calculated as the time interval between the end of a sentence and the beginning of the next one;
– T_{pause}: pause duration (in seconds), calculated as the sum of breaks inside a sentence;
– D: Duty Cycle, defined as the percent of voiced time with respect to the sentence duration;

$$D = \frac{T_{sentence} - T_{inter} - T_{pause}}{T_{sentence}} \times 100 \qquad (1)$$

– NSR: Net Speech Rate in syllables/s, defined as the number of syllables of the sentence, divided by the effective speech time ($T_{sentence} - T_{inter} - T_{pause}$)[13].

A customized algorithm was developed under Matlab R2012a tool for the extraction of these features, while the voiced-unvoiced segmentation was performed using the software BioVoice2 [14].

A two-tailed t-test was applied to assess the significance of differences between the two groups. Statistical analysis was performed with Microsoft Excel 2010.

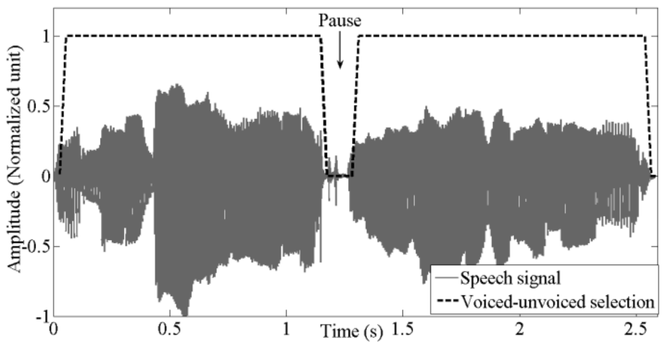

Fig. 1: Voiced-unvoiced segmentation performed on the standardized sentence used in this study.

III. RESULTS

Mean values and standard deviations of parameters are reported in Tab. I. As not all participants had breaks inside sentences, the parameter T_{pause} was considered only for D and NSR calculation.

From these results it can be noticed that significant differences exist between the two groups for parameters T_{inter} and D. In particular, the time interval between two adjacent sentences is larger in PD patients ($p = 0.01$), while duty cycle is larger in the control group ($p = 0.007$). Also NSR is larger in PD patients, although this difference is not significant ($p = 0.057$). No significant differences were found in the $T_{sentence}$ parameter.

A weak positive correlation exists between disease duration (number of years) and $T_{sentence}$ ($R = 0.50$), T_{inter} ($R = 0.41$) and NSR ($R = 0.20$), while the correlation with D is negative ($R = -0.35$).

At visual inspection no significant trend or pattern (increasing or decreasing) during the sentence repetition task was found in these four parameters.

Table I: Summary of the results with mean values, standard deviations and significance of differences between control and PD patients

	Controls		PD patients		
	Mean	S.D.	Mean	S.D	p
$T_{sentence}$ (s)	2.96	0.54	3.44	1.25	0.24
T_{inter} (s)	0.55	0.28	0.94	0.38	**0.01**
D (%)	79.59	7.79	65.66	13.94	**0.007**
NSR (syll/s)	6.14	0.66	7.00	1.32	0.057

IV. DISCUSSION

The results of this study show that PD patients exhibit an alteration of prosodic patterns of speech during a sentence repetition task. With respect to control subjects, PD patients have longer pauses between two consecutive sentences and a lower percentage of "speech time" during an entire repetition period. Decrease of duty cycle leads to an increase of NSR, as shown in eq. (1). Therefore, PD patients tend to repeat the same sentence in a shorter time period than healthy controls, but at the expense of a longer recovery time, since no significant difference was found in the $T_{sentence}$ parameter.

This findings are in accordance with other studies. Skodda et al. [9] showed that PD patients have an articulatory acceleration in the early stages of the disease, followed by slowdown in advanced stages. Our findings may be due to the presence of an early stage group of Parkinsonians as disease duration is similar to that in Skodda et al. [9] (7.2 years vs 6.44). It will be highly interesting to carry out a new test on these patients to look for possible slowdown of speech rate. Furthermore, the increase of speech rate seems to be prevalent in male patients. The larger number of male patients with respect to females seems to substantiate this argument, although hereafter it will be necessary to take into account a gender-based analysis.

At first glance, our results on T_{inter} (time interval between two consecutive sentences) could be in contrast to findings in [9] where PD patients (both males and females) showed a less percentage of pauses than healthy controls. In fact, in our study, the pause between two sentences is on average higher in PD patients than in control group. However, it should be noted that in [9] the task is not the repetition of a sentence, but the reading of a passage composed by 4 sentences.

Other studies show that alterations in speech rhythm could be pointed out by the widespread syllable repetition task (repetition of syllables /pa/ or /pa/ /ta/ /ka/). It was shown that this test can reveal vocal pace variations, with articulatory acceleration [11][14]. Thus, it will be very interesting to correlate the variations of speech rate shown by our test with those obtained from the syllable repetition task.

The advantage of our method is that the chosen sentence (which consists mainly of vowel sounds) not only allows an automatic segmentation within the whole signal, but also the estimation of other acoustic parameters (fundamental frequency, jitter, shimmer, noise, etc.). In fact, as reported in [12], one of the most discriminative acoustic measures in the analysis of speech and voice of PD is the variation of fundamental frequency during a monologue. However a free monologue task would not be useful for an automatic (and possibly remote) identification of hypokinetic dysarthria since it does not allow for comparing participants. Moreover, Skodda et al. [16] showed that tVSA (total Vowel Space Area) and VAI (Voice Articulation Index), calculated from the first and the second formant frequencies of the vowels /a/, /i/ and /u/, are predictive of PD progression. Since our sentence ("*Il bambino ama le aiuole della mamma*") contains all these vowels, it would be possible to evaluate also these parameters.

Future work will concern the kinematic analysis of articulators (in particular jaw and lips) during speech. It was shown that, during a sentence repetition task, PD patients have lower amplitude and speed of lower lips in the articulation of syllables that contains plosive consonants [17] with respect to control subjects. The implementation of marker-less technology for face tracking would be beneficial, since it can be used together with acoustic measures of voice.

Thus future work will concern the automatic extraction of acoustic and kinematic measures from this sentence repetition task, in order to identify alterations in rhythmicity, acoustic and kinematic parameters related to voice articulation, to identify and quantify hypokinetic dysarthria in Parkinson disease.

V. CONCLUSION

This study presents some preliminary results on rhythmic alterations of speech in PD patients during a sentence repetition task. It was shown that patients with Parkinson's disease may present a higher speech rate but longer time between two repetitions with respect to control subjects. These differences could be useful for an automatic real-time classification of PD speech, in order to develop a classification algorithm for early diagnosis and for tracking the disease progression.

Further studies will concern the acoustic analysis of speech samples as related to kinematic marker-less analysis of articulators in order to find other differences related to dysprosody in Parkinson's disease.

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